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Technical note

# Mechanical performances of steel fiber reinforced high strength concrete disc under cyclic loading

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ABSTRACT

A comparative study on high strength concrete discs reinforced with steel fibers under monotonic loading and cyclic loading was conducted in this contribution. A total of 40 specimens with steel fiber volume fraction ranging from 0.0% to 4% were tested. An investigation was performed on the influences of steel fiber volume fraction on fracture pattern, load-displacement response, deformation and strength. The influences of loading conditions on the mechanical performances of test specimens were also discussed in detail. Based on the experimental results, empirical equations for predicting the disc strength and deformation of high strength concrete reinforced with steel fibers were proposed.



## 1. Introduction

High strength concrete, which has been extensively adopted in long-span bridges, high-rise buildings, piles and underground structure in high ground stress, etc., can provide many structure advantages in terms of strength, stiffness and structure, and thus lead to high load capacity, small cross-section and low costs [1–6]. However, the laboratory tests indicated the high strength concrete always behaved in a brittle manner that the load rapid decrease in the post-peak stage [7–10]. In order to guarantee a ductile behaviour of the high strength concrete, the steel fibers are always included into the concrete matrix to obtain high ductility and deformability of concrete.

Considerable experiments, analytical studies and numerical modeling have therefore been conducted to investigate the mechanical performance of steel fiber reinforced concrete. A stress-strain response for fiber reinforced concrete was suggested by Fanella and Naaman [11] after a series of laboratory tests. Hsu and Hsu [12] also carried out tests to obtain the stress-strain responses of steel fiber reinforced high strength. Ezeldin and Balaguru [13] proposed a stress-strain response of fiber reinforced concrete with concrete strength ranging from 35 MPa to 85 MPa. Nataraja et al. [14] suggested a theoretical model for the steel fiber reinforced concrete, which consists of two branches, the ascending and descending ones. The mechanical performances of steel fiber reinforced high strength concrete compared with the plain concrete were carefully studied by Lim and Nawy [15]. The influences of steel fibers were tested by Foster and Attard [16] through the concentric or eccentric compression of concrete columns. Foster [17] also investigated the influences of steel fibers on the c ductility of concrete columns. Tokgoz et al. presented an experimental study on the behaviour of eccentrically loaded plain and steel fiber high strength reinforced concrete and concrete-encased composite column. Ramakrishnan et al. [18] indicated that the hookedend steel fibers can enable the concretes to withstand more impact loads and that the fibers provide at least a fivefold increase in the impact resistance. Eren and Celik [19] investigated the influences of steel fibers on concrete strength and indicated that the fiber volume and fiber aspect ratio governed the compressive strength of the concrete.

Most of the previous work focuses on the behaviour of steel fiber reinforced concrete under static load. These studies are fundamental and have contributed to a better understanding of the behaviour of steel fiber reinforced high strength concrete, which has in turn led to a higher quality design and an increase in safety. However, the mechanical performances of steel fiber reinforced concrete under cyclic loading are still unclear.

This research study focuses primarily on the mechanical performances of steel fiber reinforced concrete under fatigue splitting. A total of 40 concrete discs were tested with different steel fiber con-

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tents. 20 discs were tested under fatigue splitting and the other discs were tested under monotonic loading for comparing purpose.

## 2. Specimen preparations and testing

The Portland cement was adopted with crushed stone having a maximum particle size of 5 mm and fine sand having a fineness modulus of 2.6. The 13-mm long steel fibers with a diameter of 0.2 mm were used. The concrete mix proportions were summarized in Table 1. The tensile strength, elastic modulus and percentage elongation for the steel fibers were 2500 MPa, 210 GPa and 4%. As listed in Table 2, four groups of specimens were tested, and the fiber volume fraction ($\varphi$) was 0% (A group), 1% (B group), 2% (C group) and 4% (D group), respectively.

The steel fibers were added after the concrete ingredients were mixed. Then the ASTM Standard mixing procedure was followed of 3-min mixing, 3-min rest, and 2-min mixing. The mixed steel fiber-reinforced concrete was firstly casted in the wood mould with the dimension of $200 \times 200 \times 120$ mm. Then the specimens were placed in a 28°C room for curing after removal from the mold 24 h later. After 28 days, the specimens were cored in the laboratory using a 50 mm diameter drill bit and machined to the desired sizes. According to the ISRM suggested method [20] the diameter and height of these specimens were 49.9 mm and 25 mm, respectively, giving a thickness-to-diameter ratio ($t/d$) of 0.5. The errors in specimen dimensions were within ±0.5 mm, and the parallelism of the specimen ends was within ±0.02 mm after hand polishing. Other parameters for the concrete were listed in Table 3.

All specimens were tested under a universal testing machine with a capacity of 1500 kN. Fig. 1 gave a general view of the test setups. The applied load was controlled and measured by the electronic load transducer. The loads were applied by two steel wires between the loading plate and the specimens. The deformations of the tested specimen were measured by the displacement transducers in $x$ direction and $y$ direction. During the loading process,

**Table 1**
Concrete mix proportions (kg/m$^3$).

| Group ID | Cement | Sand | Aggregates | Silica fume | Steel fiber | Water reduce | Water |
|---|---|---|---|---|---|---|---|
| A | 780 | 412 | 620 | 246 | 0 | 20.5 | 195 |
| B | 780 | 412 | 620 | 246 | 76.3 | 20.5 | 195 |
| C | 780 | 412 | 620 | 246 | 152.6 | 20.5 | 195 |
| D | 780 | 412 | 620 | 246 | 305.2 | 20.5 | 195 |

**Table 2**
Materials parameters and test results for disc.

| Loading | Q/% | Specimen ID | $D$/mm | $L$/mm | $P$/kN | $R_L$/MPa | $X$/mm | $Y$/mm |
|---|---|---|---|---|---|---|---|---|
| Monotonic Loading | 0 | A6 | 49.7 | 28.8 | 12.19 | 5.42 | −0.116 | 0.470 |
| | | A7 | 49.7 | 28.8 | 9.61 | 4.27 | −0.087 | 0.252 |
| | | A8 | 49.7 | 28.8 | 15.39 | 6.85 | −0.113 | 0.41 |
| | | A9 | 49.7 | 28.8 | 13.75 | 6.11 | −0.161 | 0.645 |
| | | A10 | 49.7 | 28.8 | 14.08 | 6.26 | −0.106 | 0.682 |
| | 1 | B6 | 49.7 | 28.8 | 16.52 | 7.34 | −0.151 | 0.344 |
| | | B7 | 49.7 | 28.8 | 15.75 | 7.00 | −0.116 | 0.392 |
| | | B8 | 49.7 | 28.8 | 13.97 | 6.21 | −0.091 | 0.437 |
| | | B9 | 49.7 | 28.8 | 13.86 | 6.16 | −0.083 | 0.551 |
| | | B10 | 49.7 | 28.80 | 17.67 | 7.86 | −0.130 | 0.615 |
| | 2 | C6 | 49.7 | 28.8 | 20.87 | 9.28 | −0.236 | 0.704 |
| | | C7 | 49.7 | 28.8 | 15.83 | 7.04 | −0.192 | 0.633 |
| | | C8 | 49.7 | 28.8 | 19.68 | 8.75 | −0.143 | 0.403 |
| | | C9 | 49.7 | 28.2 | 23.02 | 10.46 | −0.263 | 0.598 |
| | | C10 | 49.7 | 28.8 | 20.49 | 9.11 | −0.207 | 0.676 |
| | 4 | D6 | 49.7 | 28.8 | 24.76 | 11.01 | −0.228 | 0.690 |
| | | D7 | 49.7 | 28.8 | 19.21 | 8.54 | −0.172 | 0.538 |
| | | D8 | 49.7 | 28.8 | 23.64 | 10.51 | −0.240 | 0.811 |
| | | D9 | 49.7 | 28.8 | 23.42 | 10.41 | −0.231 | 0.854 |
| | | D10 | 49.7 | 28.8 | 27.28 | 12.13 | −0.258 | 1.006 |
| Cyclic loading | 0 | A1 | 49.7 | 28.5 | 13.14 | 5.9 | −0.081 | 0.471 |
| | | A2 | 49.7 | 27.9 | 15.16 | 6.96 | −0.118 | 0.901 |
| | | A3 | 49.7 | 28.2 | 11.16 | 5.07 | −0.210 | 0.584 |
| | | A4 | 49.7 | 28.2 | 11.17 | 5.07 | −0.145 | 0.782 |
| | | A5 | 49.7 | 28.2 | 9.17 | 4.16 | −0.0701 | 0.551 |
| | 1 | B1 | 49.7 | 27 | 12.84 | 6.09 | −0.270 | 1.335 |
| | | B2 | 49.7 | 28.6 | 17.14 | 7.68 | −0.285 | 1.113 |
| | | B3 | 49.7 | 28.4 | 15.13 | 6.82 | −0.179 | 0.622 |
| | | B4 | 49.7 | 28.4 | 15.14 | 6.83 | −0.116 | 0.819 |
| | | B5 | 49.7 | 28.3 | 13.2 | 5.98 | −0.285 | 0.833 |
| | 2 | C1 | 49.7 | 29.3 | 19.11 | 8.35 | −0.451 | 1.312 |
| | | C2 | 49.7 | 29.6 | 17.15 | 7.42 | −0.099 | 0.546 |
| | | C3 | 49.7 | 28.6 | 20.49 | 9.18 | −0.407 | 1.066 |
| | | C4 | 49.7 | 28.7 | 19.12 | 8.53 | −0.256 | 1.225 |
| | | C5 | 49.7 | 29.3 | 17.14 | 7.49 | −0.2069 | 0.872 |
| | 4 | D1 | 49.7 | 29.4 | 21.12 | 9.2 | −−0.314 | 1.081 |
| | | D2 | 49.7 | 28.4 | 27.05 | 12.2 | −0.589 | 1.685 |
| | | D3 | 49.7 | 28.6 | 21.07 | 9.44 | −0.328 | 1.078 |
| | | D4 | 49.7 | 32.5 | 21.09 | 8.31 | −0.398 | 1.049 |
| | | D5 | 49.7 | 28.2 | 23.06 | 10.47 | −0.429 | 1.335 |